CONTROL OF CONTAMINANT EMISSIONS FROM FOSSIL FUEL-FIRED BOILERS *

by

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INTRODUCTION

There are at least three basic environmental elements which must be considered when examining the needs and the future of mankind. These are land, water and air. For the most part, land and water have been recognized as limited resources and society has been fairly astute in developing methods for their conservation and improvement. Society has not been so discerning, however, with regard to the third element, without which we would cease to exist. The air we breathe has traditionally been regarded as a free and inexhaustible commodity. For years it has been used as an aerial dumping ground for noxious, odorous, and toxic vapors and gases and other contaminating materials. Because of its vastness, it is often difficult to conceive that man's activities could seriously affect its quality. Only recently have all segments of this country become aware that there are real and observable limits to the extent to which man can continue to contaminate this precious resource. We have come to realize that we can no longer encroach upon the air we breathe and that something must be done to prevent its further deterioration.

In terms of need, the air we breathe is of paramount importance. In terms of the actual volumes inspired, our needs are comparatively small, however, when contrasted with the tremendous volumes of air consumed in combustion processes. It has been estimated that each person in the world has about sixty billion cubic feet of air at his disposal. Since the average daily personal intake for breathing is only about three to four hundred cubic

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feet, the air supply would seem to be almost inexhaustible. Population densities, meteorological conditions and topographic factors, however, impose restrictions in some areas on the available supply. For example, in the Los Angeles Basin, when the inversion base is at one thousand feet, there is available roughly five million cubic feet of air per person. On a day of severe smog, the inversion base may be as low as 100 feet, so that the air available is only one-tenth as much or about five hundred thousand cubic feet per person. This is about the same volume of air that the air conditioning industry has estimated is required by a person for his comfort. Air required for the combustion of fuels in the Los Angeles Basin approximates five to six thousand cubic feet per person per day. In terms of actual weight, more air than fuel is used in all combustion processes, including the burning of gasoline in motor vehicles or the burning of fuel oil and coal in steam-electric generating power plants. These combustion processes deplete the natural supply of oxygen in the air and replace it with potentially harmful air contaminants. Thus, the available supply of air is diminished as the demands placed on it become greater.

An eminent scientist and international expert on air pollution recently warned that, "the world's atmosphere will grow more and more polluted until a century from now it will be too poisonous to allow human life to survive--". This statement may seem rather dramatic, but others have also expressed a similar concern about air pollution. The late President Kennedy underlined this concern in his 1962 health message to Congress when he said, "Fresh air cannot be piped into the cities nor can it be stored for future use. Our only protection is to prevent pollution". President Johnson in his message last year to the Congress pointed out that air pollution is no longer confined to isolated places and referred to the health hazard present as a result of air pollution, along with loss of efficiency, reduction in property values, and added costs to the nation. He referred to motor vehicle pollution and to many other sources, particularly the contribution of stationary combustion sources and to the extent that sulfur dioxide and other contaminants were being added to the atmosphere from the burning of fossil fuels.

The effects of air pollution are many and varied and all are objectionable and undesirable. Polluted air is harmful to our health, it damages vegetation and property, offends our senses and lessens our enjoyment of life. Without a doubt, the most serious problem in air pollution today is that which results from the combustion of fuels.

AIR POLLUTION FROM COMBUSTION SOURCES

The extent of an air pollution problem may be measured in a variety of ways--in terms of quantities of contaminants emitted, atmospheric concentrations, and in terms of effects such as health, damage to vegetation, reduction in visibility, rubber cracking, or just plain dirt. The acute effects of air pollution on health are well documented by disasters in England and in the United States. We know from these incidents that prolonged periods of atmospheric stagnation can result in a build-up of contaminant concentrations which can be lethal. The effects on health from continued exposure to lesser concentrations of air contaminants are not so well documented but are nevertheless recognized by the medical profession. It is noteworthy that high atmospheric concentrations of sulfur compounds have been associated with each of the disaster incidents. For the purpose of this discussion we will examine the air pollution problem from combustion sources in terms of emissions.

Nationally, the air pollution sources requiring the highest priority of attention are motor vehicles and fuel burning, principally for steam-electric power generation. The importance of fuels combustion processes was brought into sharp focus recently in a staff report on air pollution to the Committee on Public Works of the United States Senate [1/], in which it was stated, "These processes replace usable air with potentially harmful pollutants, and the capability of the atmosphere to disperse and dilute these pollutants--especially in urban areas where people, vehicles, and industries congregate in even greater numbers--is strictly limited."

The burning of fossil fuels generates a variety of air contaminants ranging from visible aerosols to invisible inorganic and organic gases. Aerosols is a generic term used to include all solid and liquid particulate matter, including ash, carbon, and sulfur trioxide. The gaseous combustion contaminants include oxides of nitrogen, sulfur dioxide, hydrocarbons, and carbon monoxide. The combustion products from boilers and heaters are sulfur dioxide and its oxidation products, oxides of nitrogen and particulate matter. Carbon monoxide and hydrocarbons are the products of incomplete combustion. The principle source of carbon monoxide and hydrocarbon emissions to the atmosphere is the motor vehicle. In contrast to motor vehicle emissions, the production of carbon monoxide and hydrocarbons from boilers and heaters is virtually negligible. The overwhelming burden of emissions of sulfur oxides, oxides of nitrogen and particulates in the United States today is that originating from the burning of coal and fuel oil in stationary combustion sources. Thus, combustion has a large influence on the quality of the atmosphere in most urban areas. Some of the contaminants from combustion processes are objectionable in the form in which they are emitted, while others are converted into objectionable products after they enter the atmosphere. The best known example is the reaction involving hydrocarbons and oxides of nitrogen in the presence of sunlight resulting in the production of eye irritating and visibility reducing materials contributing to the characteristic conditions often referred to in Los Angeles County as "smog".

Aerosols and Visible Plumes

For many years visible smoke plumes have been the most obvious manifestation of air pollution from combustion processes. Plumes varying in color from grey to black are produced by finely divided carbon particles entrained in the effluent. This plume phenomenon usually occurs from the combustion of coal and fuel oil. A black smoke plume is indicative of inefficient utilization of fuel and for the most part is not tolerated in large industrial operations. Fuel economy is not equally important, unfortunately, in the operation of most small industrial, commercial and residential installations; and, as a result, these are chief sources of smoke. The obvious remedy for smoke pollution is proper combustion equipment, improved operation and better fuels.

White or yellowish smoke plumes from oil fired boilers and heaters are due principally to sulfur trioxide present in the stack effluent and, to some extent, to particulates which are microscopic in size, varying from one micron to less than one-half micron in diameter. The light scattering ability of particles in this size range is most pronounced. The quantities of particulates from fuel oil combustion are small when compared with those produced by coal burning. Tests on power plant steam generators show that sulfur trioxide in concentrations of as little as 3 parts per million cause a visible plume. At stack concentrations of 15 ppm of SO_3, a conspicuous plume was emitted [2/]. This kind of a stack plume cannot be eliminated by more efficient combustion methods. Typical stack gas particulate loadings for an oil-fired steam generator without controls vary from 0.02 to 0.03 grain per standard cubic foot. A comparable coal-fired unit will produce stack concentrations of the order of 1.5 to 4 grains per std. cu. ft. Removal of sulfur trioxide and sub-micron particulates by mechanical collection and electrostatic precipitation has proven unsuccessful for plume control.

Sulfur Dioxide

Quantitatively, sulfur dioxide is the most significant combustion contaminant. The role of sulfur dioxide in atmospheric pollution has received a great deal of investigation and public attention in the past and is now recognized as a most important air contaminant. With pulverized coal firing, 95 per cent or more of the sulfur in the coal is converted to SO_2 and discharged in the stack effluent. A small amount of the sulfur in the coal may remain in the ash [3/] With fuel oil firing, virtually all of the sulfur is discharged as SO_2. Approximately 1 to 3 per cent of the total sulfur oxides are discharged as SO_3.

Oxides of Nitrogen

Oxides of nitrogen are the other important air contaminants produced from the burning of coal and fuel oil; and, to a lesser extent, from natural gas. In all combustion processes, some of the nitrogen in the air required for combustion is fixed as nitric oxide. Boiler furnaces, particularly the water-wall types used in large steam generators, offer extremely favorable conditions for the formation of nitrogen oxides. Flame temperatures can exceed 3000°F. in these furnaces and both oxygen and nitrogen are present in appropriate concentrations for fixation to occur. The extent of fixation is influenced primarily by flame temperature and length of time that the combustion air is in contact with the high temperature flame zone. Other factors influencing the fixation may be classified generally as fuel variables, operating variables, burner and furnace design variables. Coal usually produces a higher yield of nitrogen oxides than fuel oil, with the least amount being produced by natural gas.

Dimensions of the Problem

The principle sources of emissions of the three major air contaminants--aerosols, oxides of sulfur and oxides of nitrogen--are the combustion of fuels for heat generation for industrial uses, space heating, thermoelectric power generation and for transportation. These sources may be divided into two broad categories--stationary sources and moving sources. Moving sources encompass trains, ships, aircraft and motor vehicles. For purposes of comparison here, however, we will use only motor vehicles as this is the major contributor. The burning of fuels in stationary combustion sources is the major source of air pollution in the nation today.

Based on the 1965 consumption estimate of 70 billion gallons of gasoline, motor vehicle emissions, as shown in Table I, amounted to approximately 4.75 million tons of nitrogen oxides, 150,000 tons of sulfur oxides and 425,000 tons of particulates. 4/

TABLE I

EMISSIONS OF AIR CONTAMINANTS FROM MOTOR VEHICLES IN THE UNITED STATES, 1965

CONTAMINANT	THOUSANDS OF TONS PER YEAR
Nitrogen Oxides	4745
Sulfur Oxides	150
Particulates	425
Gasoline Consumption -- 70,000,000 Gallons Per Year	

The burning of coal, fuel oil and natural gas contributes over 6.6 million tons of nitrogen oxides or nearly 2 million tons more than that produced by motor vehicles. Stationary combustion sources contribute over 99 per cent of the sulfur oxides produced and approximately 95 per cent of the total particulate emissions, as shown in Table II.

TABLE II

COMPARATIVE EMISSIONS OF AIR CONTAMINANTS FROM MOTOR VEHICLES AND COMBUSTION OF FUELS IN STATIONARY SOURCES IN THE UNITED STATES, 1965

Source	Contaminant Emissions, In Thousands of Tons/Year		
	Nitrogen Oxides (as NO_2)	Sulfur Oxides (as SO_2)	Particulates
Motor Vehicles	4,745 (42%)	150 (1%)	425 (5%)
Stationary Combustion Sources	6,600 (58%)	20,800 (99%)	7,640 (95%)
Totals	11,345 (100%)	20,950 (100%)	8,065 (100%)

In Table III a summary is shown of the approximate quantities of coal, fuel oil and natural gas burned annually in the nation and the annual rate of emissions of nitrogen oxides, sulfur oxides and particulates. The total of these three fuels burned annually approximates over 5 billion equivalent barrels. Of this total, coal and fuel oil, including both distillate and residual fuel oils, supply in nearly equal proportions approximately 50 per cent of the total fuel requirements in the United States. The remaining 50 per cent, or approximately 2.5 billion equivalent barrels, is supplied by natural gas. In the order of their pollution potential, coal burning is uppermost, with fuel oil second in importance and natural gas third. Coal burning in stationary sources produced approximately 3 million tons of nitrogen oxides, or over 45 per cent of the total quantity emitted by all stationary fuel burning sources. Fuel oil burning resulted in emissions of 2.1 million tons and natural gas, 1.5 million tons. The burning of coal is also the major source of sulfur oxides emissions. Combustion of coal produces 16 million tons or 77 per cent of the annual emissions of sulfur oxides. Fuel oil burning results in emissions of about 4.8 million tons or 23 per cent of the total annual emissions of this contaminant. Emissions of sulfur oxides from natural gas are negligible.

TABLE III

ESTIMATED ANNUAL FUEL CONSUMPTION AND EMISSIONS FROM COMBUSTION OF FUELS IN STATIONARY SOURCES IN UNITED STATES, 1965

Fuel Type	Millions of Equiv. Bbls.(a)	Contaminant Emissions, Thousands of Tons/Year: Nitrogen Oxides (as NO_2)	Sulfur Oxides (as SO_2)	Particulates
Coal	1300 (25%)	3,000 (45%)	16,000 (77%)	7,000 (92%)
Fuel Oil	1250 (25%)	2,100 (32%)	4,800 (23%)	540 (7%)
Natural Gas	2500 (50%)	1,500 (23%)	Negligible (b)	100 (1%)
Totals	5,050 (100%)	6,600 (100%)	20,800 (100%)	7,640 (100%)

(a) Fuel Oil Heat Equivalents: 1 Ton of Coal = 4 Bbls. of Fuel Oil = 24,000 Cu. Ft. of Natural Gas

(b) Less Than 3000 Tons Per Year

The Future

We can expect that air pollution effects will increase at least in proportion to increases in emissions. The most dismal outlook for the future is to assume that there will be no changes in control technology and in current control efforts; consequently, future emissions would be calculable by applying factors which represent estimates in the increase in the number and the size of sources accompanying increase in fuel use at some future date. Almost every projection of social and economic activity between now and the year 2000 indicates that fuel use and emissions will multiply many fold. Over a quarter of a million industries in the nation are expected to double their activities every 20 years; pollution from thermal power production is expected to increase at a rate of some 20 per cent each year. Forcasts have been made by some authorities which indicate that, by the year 2000, fifty per cent of the U.S. electric generating capacity will be nuclear; nevertheless, it is expected that fossil-fuel fired steam-electric generating capacity will double by 1980 and redouble by the year 2000. Another appraisal has been made on the assumption of controls at the maximum level that technology will allow. Such estimates show, in the case of SO_2 emissions, a 20 per cent increase by 1980 and a 20 per cent decrease by the year 2000. This means that if everything technically possible is done, pollution will "break even" by the year 2000.

CONTROL OF COMBUSTION CONTAMINANTS

Today, while we still do not know all we would like, we have learned a great deal about air pollution and its control, and there are very few industrial emissions that cannot be controlled. Much technology is available which is not now being used in the control of pollution from combustion sources. Often the reasons for this are not technical but social and economic.

The unit processes of contaminant removal from combustion effluents are particulate removal by filtration, centrifugal separation, electrostatic precipitation, fabric filtration; and gas or vapor removal by absorption, adsorption or scrubbing. Some systems use intermediate steps such as agglomeration to aid particulate removal, the use of additives or chemical reaction to change the character of the gas or vapor to aid in its removal. Sufficient knowledge is available about each of these processes to enable the design of systems for particulate, gas and vapor removal where contaminant concentrations are relatively high. However, at lower concentrations current control methods become increasingly difficult and costly, to the point where, as in the case of removal of sulfur dioxide from combustion effluents, new technology is needed. In such cases, the approach to control must necessarily seek to prevent the formation of the emission.

Heat Generation for Industrial Uses and Space Heating

The technology to reduce air pollution effects from emissions associated with heat generation and space heating includes:

1. Promotion of more efficient combustion of fuels assisted by equipment standards and ordinances.

2. Stringent fuel specifications with respect to ash, sulfur, volatility, etc.

3. Methods to reduce emissions of nitrogen oxides.

4. Restriction of fuel types.

5. Substitution of natural gas for oil or coal.

Generation of Electricity

The technology to reduce air pollution effects from emissions associated with the generation of electricity includes:

1. Increasing plant efficiency so that less fuel is needed to produce a given amount of energy.

2. Increasing the efficiency of power distribution and utilization so that total energy requirements are lessened.

3. Increasing the use of nuclear and hydroelectric generation systems.

4. Reducing the emissions of contaminants produced by fossil-fuel burning power plants by such means as:

   a. For sulfur oxides emissions,

      (1) Use of lower sulfur bearing fuels.

      (2) Use of means for removing sulfur oxides from the effluent.

   b. For nitrogen oxides emissions,

      (1) Use of fuels which produce lesser amounts of nitrogen oxides.

      (2) Use of means for preventing the formation of nitrogen oxides.

   c. For particulate emissions,

      (1) Use of fuels which produce lesser amounts of particulates.

      (2) Use of more efficient particulate collection equipment.

Technology is not too adequate today for controlling the contaminants emitted from fossil-fuel fired steam generators, particularly sulfur oxides and nitrogen oxides emissions. More often than not, the problem of air pollution from the combustion of fuels is only solvable in a relatively straight-forward manner, such as by the substitution of fuels. This has been the approach to control adopted by the Air Pollution Control District of Los Angeles County. A similar but much less stringent effort to control emissions from combustion sources was recently adopted by the City of New York.

LOS ANGELES COUNTY VS. NEW YORK CITY - A CASE STUDY

In New York City, sulfur dioxide is considered one of the major air contaminants. A recent Public Health Service study of more than 40 cities showed that New York has the highest average (0.16 ppm) and also experiences the highest average yearly maximum (0.37 ppm) atmospheric concentrations of sulfur dioxide[5/]. The primary source of sulfur dioxide emissions in the City is the burning of fuel oil and coal in stationary combustion sources. In October 1964, New York City adopted an ordinance limiting the sulfur content of solid fuel and residual fuel oil to 3.0 per cent. This is to be progressively reduced to 2.2. per cent over a period of 5 years. The ordinance also restricts the sulfur content of No. 2 fuel oil to 1 per cent. A recent survey of fuel use showed that No. 6 fuel oil burned in the City currently averages 2.31 per cent. Other fuel oils as well as coal now used in the City already meet or are substantially lower in sulfur content than that ultimately required by the ordinance. In essence, the ordinance restrictions are inadequate to curb emissions of sulfur dioxide. In fact, emissions of this contaminant can be expected to increase many fold just as fuel requirements will increase. No processes or equipment have yet been advanced that will reduce substantially all of the contaminants that result from the combustion of solid and liquid fuels. Some progress has been made, however, in methods for removing some of the sulfur compounds and some of the particulates. In view of this, it has been the official determination of the Los Angeles County Air Pollution Control District that the only practical approach to the control of emissions of these contaminants from stationary combustion sources is to use natural gas as a fuel.

Comparative Statistics for New York City and Los Angeles County

The following analysis of fuel usage in New York City in 1964 is based on the fuel consumption estimates found in the City Council Report M-970 (Low Report) and on data obtained from the Consolidated Edison Company and the Air Pollution Control Department of New York City. To facilitate fuel use comparisons shown in Table IV, the quantities of the various types of fuels used are expressed in terms of equivalent barrels of fuel oil.

New York City has a land area of 320 square miles, or roughly one-twelfth of that in Los Angeles County. It has a population of over 8 million or more than 1 million greater than Los Angeles County. In 1964 the total energy and heating requirements of the City required the burning of nearly 140,000,000 equivalent barrels of fuel oil. This fuel requirement was nearly 25 per cent greater than that of Los Angeles County in the same year. Of greater significance, however, is the manner in which these fuel requirements were met. Approximately 20 per cent of the total of all fuels burned was coal and 60 per cent was fuel oil which, in large part, was a high sulfur bearing residual type of oil. The remaining 20 per cent of the total fuel requirements was supplied by natural gas. Of the total gas consumed, over 32 per cent was burned by Consolidated Edison Company. By contrast, in Los Angeles County, approximately 80 per cent of the total fuel requirements were supplied by natural gas. No coal is burned in Los Angeles County, and for all practical purposes, the only fuel oil burned is that which is burned by power plants and refineries out of necessity when natural gas supplies are curtailed to these consumers during the period from November 16 to April 14.

TABLE IV

COMPARATIVE STATISTICS FOR NEW YORK CITY AND LOS ANGELES COUNTY, 1964

	Los Angeles County	New York City
Population	6,800,000	8,000,000
Land Area, Sq. Miles	4,083	320
Steam-Electric Utilities		
No. of Plant Locations	11	16
No. of Boilers	60	107
Steam Generation, M lbs/hr	35,000	45,000

Summary of Fuels Consumed--Equivalent Barrels *

	Los Angeles County		New York City	
Coal	0	(0%)	27,848,000	(20%)
Fuel Oil	9,574,000	(8%)	82,752,000	(60%)
Natural Gas	89,505,000	(80%)	29,270,000	(20%)
Refinery Make Gas	14,337,000	(12%)	(Unknown)	
Totals	113,416,000	(100%)	139,870,000	(100%)

Contaminant Emissions from the Combustion of Fuels, Tons Per Day

	Los Angeles County		New York City	
	Avg. Space Heating Day	Max. Space Heating Day	Avg. Space Heating Day	Max. Space Heating Day
Particulate Matter	20	75	380	725
Nitrogen Oxides (as NO_2)	195	380	615	1030
Sulfur Oxides (as SO_2)	15	660	1800	2965

* One ton of coal is the heat equivalent of 4 barrels of fuel oil.

The burning of fuels in stationary combustion sources on an average space heating day in New York, as shown in Table IV, produces 1800 tons of sulfur oxides, over 600 tons of nitrogen oxides and 380 tons of particulates. On a comparable space heating day in Los Angeles County, the burning of fuels produces only 15 tons of sulfur oxides, about 200 tons of nitrogen oxides and 20 tons of particulates. On a maximum space heating day in New York City, fuel burning in 1964 produced nearly 3000 tons of sulfur oxides, over 1000 tons of nitrogen oxides and 725 tons of particulates. In contrast, in Los Angeles County, on a maximum space heating day, fuel burning produced 660 tons of sulfur oxides, 380 tons of nitrogen oxides, and 75 tons of particulates.

Control of Fuel Oil Burning in Los Angeles County

The industrial fuel requirement of Los Angeles County are met in quite a different manner from that of the rest of the country. Together, fuel oil, natural gas and refinery produced fuel gas supply essentially 100 per cent of the County's fuel requirements. In terms of total air contaminants emitted to the atmosphere, fuel oil burning by industry, including a refinery complex which is the third largest in the nation, and particularly by steam-electric generating power plants, is a major contributor. Fuel oil burning is the largest source of sulfur oxides emissions and particulates, and the second largest source of nitrogen oxides. Accompanying the unprecedented population and industrial growth of Los Angeles County has been the growth in demand for electric energy; energy which in this area is produced almost entirely by steam-electric generating power plants.

In the last fifteen years, the population of Los Angeles County has increased more than 60 per cent. In the same period of time, the thermoelectric power requirements have more than quintupled, going from 4.5 billion kilowatt-hours per year in 1950 to nearly 23 billion kilowatt-hours per year in 1964. To produce this amount of electrical energy in 1964, power plants burned the equivalent of nearly 35 million barrels of fuel oil. The total of all fuels burned in 1964 by all industry approximated 73 million equivalent barrels. In Table V a breakdown is shown of the annual consumption of fuels in 1964 by the various major source categories, both for Los Angeles County and New York City. Of particular interest is the pattern of fuel use by the commercial and residential category of consumer. In Los Angeles County, natural gas is used almost exclusively by this category of consumer, while in New York City fuel oil is the predominant fuel.

TABLE V

COMPARISON OF FUELS CONSUMED IN NEW YORK CITY AND LOS ANGELES COUNTY, 1964

	Annual Fuel Consumption, in Equivalent Barrels	
	Los Angeles County	New York City
Steam-Electric		
Coal	0	21,928,000
Fuel Oil	7,830,000	13,350,000
Natural Gas	27,020,000	9,500,000
Sub-Total	34,850,000	44,778,000
Industrial		
Coal	0	1,600,000
Fuel Oil	1,744,000	5,992,000
Natural Gas	21,604,000	3,670,000
Refinery Gas	14,337,000	(Unknown)
Sub-Total	37,685,000	11,262,000
Commercial and Residential		
Coal	0	4,320,000
Fuel Oil	Neg.	63,410,000
Natural Gas	40,881,000	16,100,000
Sub-Total	40,881,000	83,830,000
Grand Total	113,416,000	139,870,000

The need for control of pollution from fossil fuel fired boilers must consider the types and quantities of fuels consumed and the nature and magnitude of the contaminants emitted. At the same time, consideration must be given to the expected increase in thermal energy demands resulting from community growth and the air pollution potential of fossil fuels expected to supply this demand.

We have estimated that there are some 4000 boilers and heaters, including 60 large power plant steam generators, now operating in Los Angeles County which are fired either with fuel oil or natural gas or with some combination of these two fuels. The total number of individual stationary combustion sources, including small domestic and commercial units, approximates over 7,000,000. The magnitude of contaminant emissions resulting from the combustion of fuels in these sources is extremely large when compared to the total quantities of such contaminants emitted from all sources. Experience has shown that these contaminant emissions can be reduced greatly by the use of natural gas in lieu of fuel oil, and that reductions already accomplished through partial substitution of natural gas have had a measurable impact upon the air quality of Los Angeles County.

Fuel oil burning in Los Angeles County produces three times as much sulfur oxides as produced by all other sources combined, including motor vehicles; as much particulates as would be emitted by 30 completely uncontrolled open hearth steel furnaces; and as much oxides of nitrogen as one million automobiles. Steam-electric generating power plants produce nearly 90 per cent of the total of sulfur oxides, nitrogen oxides and particulates emissions from fuel oil combustion. As shown in Table VI, the burning of fuel oil in a power plant results in the emission of over seven times as much pollution as does the use of an equivalent amount of natural gas. In addition to achieving substantial reductions in nitrogen oxides, amounting to over 50 per cent, the substitution of natural gas for fuel oil results in almost complete elimination of both sulfur oxides and particulates.

In view of these findings, a responsible public agency could reach only one conclusion--that fuel oil must be replaced by a superior fuel. To curb emissions from fuel oil burning, the Los Angeles County Air Pollution Control District adopted Rules 62 and 62.1, which, in effect, require the use of natural gas in lieu of fuel oil. Total air pollution studies have shown that in 1964 these rules prevented average daily emissions of 330 tons of sulfur oxides, nearly 100 tons of nitrogen oxides and approximately 20 tons of particulates. In addition, the rules have prevented other objectively verifiable problems traceable to fuel oil burning, including the occurrence of esthetically offensive visible plumes which much of the time are also in violation of opacity restrictions, generalized reductions in visibility, damage to property and vegetation, and nuisance to a large number of the residents of Los Angeles County.

TABLE VI

COMPARISON OF AVERAGE EMISSIONS OF AIR CONTAMINANTS FROM POWER PLANTS BURNING FUEL OIL AND NATURAL GAS AND REDUCTION OBTAINED BY USE OF NATURAL GAS

Type of Air Contaminant	Comparative Emissions Pounds Per Thousand Equiv. Bbls.[a]		Reduction by Use of Natural Gas	
	Fuel Oil	Natural Gas	Lbs/1000 Bbl.	Percent
Particulate Matter	800	20	780	98
Nitrogen Oxides (as NO_2)	5,000	2,340	2,660	53
Sulfur Oxides (as SO_2)	10,930[b]	Negligible	10,930	100
TOTALS	16,730	2,360	14,370	86

(a) 6,000 cubic feet of natural gas is considered equivalent, on a heating basis, to one barrel of fuel oil.

(b) SO_2 emissions from fuel oil based on an average sulfur content of 1.54 percent and an average weight per barrel of 355 pounds.

Reductions in Fuel Oil Use Affected by Rules 62 and 62.1

Under the terms of Rules 62 and 62.1, a blanket prohibition is placed on the use of certain gaseous and liquid fuels during specified periods of the year. Fuel oils containing more than 0.5 per cent sulfur are prohibited together with gaseous fuels containing more than 50 grains of sulfur per 100 cubic feet of gas. Rule 62 is operative from April 15 to November 15 and Rule 62.1 applies during the rest of the year. The basic difference between the rules is that under Rule 62.1 a consumer is allowed to burn fuel oil when natural gas service is "interrupted" by the supplier. Under the existing gas supply situation, interruption or gas curtailment commonly occurs during the winter months due to a shortage of natural gas. Curtailment is the result of increased demand by domestic consumers for space heating requirements.

Since its adoption in 1958, virtually no fuel oil of any kind has been burned during the so-called Rule 62 period of the year, with the result that fuel oil's share of the total market has sharply declined--a condition which has been the cause of quite some considerable anxiety to the oil industry. Examination of the historic fuel use by power plants, shown in Tables VII and VIII, reveals the impact of the Rules on fuel oil usage in Los Angeles County. In terms of power plants, alone, total fuel requirements (gas plus oil) have increased from nearly 107,000,000 equivalent barrels in the five years prior to Rule 62 (1954-58) to about 148,000,000 equivalent barrels in the most recent five-year period (1960-64). This represents an increase in total fuel usage of 38 per cent. Nevertheless, total fuel oil consumption declined from 50 million barrels to about 39 million barrels in the same period, for a reduction of approximately 20 per cent.

The Rule has produced even a more dramatic decline in summertime fuel oil use. In 1957, the summertime use of fuel oil by power plants averaged over 30,000 barrels per day. In contrast, power plant fuel oil usage shrank to an almost immeasurable level in 1959, when Rule 62 became effective....5,250 barrels for the entire summer, or an average of about 34 barrels per day, and all of this was low-sulfur oil (0.5% sulfur, by wt.). Clearly, the major impact of Rule 62 and 62.1 has been to secure a substitution of natural gas for fuel oil. By contrasting contaminant emissions between natural gas and fuel oil it becomes evident how these Rules have reduced the burden of air contaminants released to the atmosphere of Los Angeles County.

TABLE VII

ANNUAL POWER PLANT FUEL USAGE 1954-58, LOS ANGELES COUNTY

Year	Total Fuel Usage * (Gas & Oil)	Fuel Oil Usage	Percent Oil of Total Fuel Usage	Annual Daily Average (Gas & Oil) **
1954	16,591,260	5,012,510	30.2%	45,700
1955	21,099,674	11,111,785	52.7%	57,800
1956	21,476,030	11,417,635	53.2%	58,000
1957	25,669,723	14,557,321	56.7%	70,300
1958	21,944,076	7,414,083	33.8%	60,100
Totals	106,780,763	49,513,333	46.4%	

* In equivalent barrels.

** Total annual fuel use ÷ 365

TABLE VIII

ANNUAL POWER PLANT FUEL USAGE 1960-64, LOS ANGELES COUNTY

Year	Total Fuel Usage (Gas & Oil)	Fuel Oil Usage	Percent Oil of Total Fuel Usage	Annual Daily Average (Gas & Oil) **
1960	26,673,886	9,274,241	34.8%	73,100
1961	27,809,771	7,976,025	28.7%	76,300
1962	29,015,380	7,327,869	25.3%	79,500
1963	29,813,973	6,571,097	22.0%	81,700
1964	34,847,698	7,830,735	22.5%	95,500
Totals	148,160,708	38,979,987	26.3%	

* In equivalent barrels.

** Total annual fuel use ÷ 365

The magnitude of the reductions obtainable by full implementation of Rules 62 and 62.1 is revealed in Table IX. Substitution of natural gas for fuel oil on the peak day of fuel oil usage in 1964 would have reduced daily emissions of sulfur oxides by 740 tons and particulate emissions by 65 tons.

TABLE IX

REDUCTION OBTAINABLE IN PEAK DAY EMISSIONS OF AIR CONTAMINANTS FROM THE BURNING OF FUELS IF NATURAL GAS HAD BEEN SUBSTITUTED FOR FUEL OIL BURNED IN LOS ANGELES COUNTY

Fuel Use Configuration	Contaminant Emissions, Tons Per Day[b]		
	Nitrogen Oxides (as NO_2)	Sulfur Oxides (as SO_2)	Particulate Matter
Actual peak day emissions from the burning of liquid and gaseous fuels[a]	435	740	90
Peak day emissions which would have resulted if natural gas had been substituted for fuel oil	265	Negligible	25
Reductions in emissions which would have been gained in natural gas had been substituted for fuel oil	170	740	65

(a) Peak day of fuel oil usage by interruptible industrial gas consumers.

(b) Emission figures rounded.

Additional Gas Supplies Needed

Although Rules 62 and 62.1 in effect ban fuel oil burning year-round in Los Angeles County, thus far both public law and policy have been frustrated by the lack of adequate gas supplies to provide for the full wintertime requirements of industry and power plants. During the fall and winter months, when gas supplies are limited, fuel oil burning contributes to a dramatic increase in atmospheric concentrations of pollution. Sulfur dioxide concentrations increase by 50 to 100 per cent; nitrogen oxide and aerosol concentrations increase by 300 to 400 per cent. In fact, nitrogen oxide concentrations have twice exceeded the District's first alert level of 3 ppm.

For over three years hearings have been in progress before the Federal Power Commission on two competing natural gas supply projects which have been specifically designed to commit major gas supplies for year-round power plant use in Los Angeles County. One is the Gulf Pacific Pipeline Company project for which the Southern California Edison Company and the Los Angeles Department of Water and Power have contracted. The other is an alternative proposal by the Transwestern Pipeline Company and the El Paso Natural Gas Company, supported by the Southern California and Southern Counties Gas Companies. The Air Pollution Control District, by order of the Board of Supervisors of Los Angeles County, intervened in these proceedings in the public interest to support certification of the project or projects which would provide the largest volumes of natural gas, at the earliest date, for the greatest number of years and at a reasonable price, to the end that industry and power plants in Los Angeles County will be able to burn natural gas exclusively on a year-round basis. The primary objective of the intervention is to secure cleaner air for Los Angeles County.

Two intervenors in the Federal Power Commission proceeding, the Western Oil and Gas Association, and one of its members, the Standard Oil Company of California, have opposed Rules 62 and 62.1 from the day that the rules were proposed. They have asserted that the burning of fuel oil can safely be ignored and that the air contaminants emitted from such combustion have no effect whatsoever on the air quality of Los Angeles County. Nothing could be further from the truth.

On December 16, 1965, Federal Power Commission Presiding Examiner Alvin A. Kurtz filed an initial decision which would authorize Gulf Pacific Pipeline Company to build a $314,000,000 pipeline to transport natural gas purchased in Texas by Edison Company and the Department of Water and Power for use as a boiler fuel in their power plants. The examiner at the same time rejected competing applications by Transwestern and El Paso for an alternative project. 6/

In his decision, Examiner Kurtz said, "The prepondence of the evidence is against the contentions of Western Oil and Gas Association and in favor of the benefits to be derived by the people in the Los Angeles Basin by the use of gas under the boilers in the power plants therein. The record here is clear that the public wants the increased level of gas service and is ready to pay for it. The benefits not only relate to the health of the people and their welfare but also to the loss of food and fibre crops in the Los Angeles area which has been estimated to be in excess of $5,000,000 annually." He added, "The advantages of using natural gas in the power plants instead of fuel oil is that no ash is found in the combustion of natural gas, no oxides of sulfur, nitrogen oxides are less than one-half the amount produced from fuel oil burning and the problem of opacity violating stack plumes is eliminated."

Examiner Kurtz continued, "Public complaint as to air pollution is continuous and wide spread, including complaints directed to the operation of steam-electric generating plants. These complaints include eye irritation and respiratory discomfort. The present atmospheric conditions in the Los Angeles Basin do present a health problem. This is borne out by the testimony of three outstanding doctors of medicine specializing in this field, called by the APCD." He went on to say, "The Los Angeles air pollution problem will not be elimirated by the increased use of gas under boilers but the reduction in tonnage of pollutants in the magnitude here under consideration will affect the concentrations of contaminants and aid in the program of the APCD to reduce air pollution to the benefit of the people in the Los Angeles Basin."
[illegible]
merits of any scientific controversy over the burning of fuel oil, are faced with regulatory prohibitions against the burning of fuel oil, public complaints about such burning and advice from the medical fraternity to its patients to the effect that air pollution is harmful. These facts, alone, impose upon Edison and Department the public duty to minimize, if not eliminate, the burning of fuel oil in their steam-electric generating plants in the Los Angeles Basin." Concerning coal burning, the Examiner said, "The Los Angeles County Air Pollution Control District has made it clear that it will not tolerate coal burning in the Los Angeles Basin." Following oral arguments before the Commission on March 29, 1966, a final decision will be rendered in this case.

In its latest attack on the Rules, the Western Oil and Gas Association filed a lawsuit in Los Angeles County in which it asked the Superior Court to declare Rules 62 and 62.1 unlawful (Superior Court No. 836, 864). The complaint alleged six causes of action. The court rejected five of the six Western Oil and Gas Association charges before trial. In the sixth charge, WOGA challenged the entire rule making power of the District under the Air Pollution Control Act adopted in 1947 by the California Legislature, and further alleged that Rules 62 and 62.1 were arbitrary, capricious and void and are a deprivation of the equal protection of the law and a deprivation of property without due process of law. On January 26, 1966, after nearly a year of litigation, the court ruled against

WOGA on the remaining charge. In his decision the judge ruled that, "The power to control the release of air contaminants clearly encompasses the power to regulate the burning of fuels since no fuel can be burned that does not emit or result in the release in the atmosphere of some kind and quantity of contaminants." He went on to say that, "Neither Rule 62 nor Rule 62.1 varies or enlarges the terms of the Act. They are consistent and not in conflict with it." Also that, "The argument that said rules are beyond the rule-making power delegated to the Board falls before the terms of the Act and the facts of this case." The judge further said, " The wisdom, propriety or necessity for Rule 62 or 62.1 is the primary function of the Board of the District and not the judiciary. If there is any rational connection between the adopted rules and the legislative purpose, the rules are impervious to attack." He added, "It is plain that there is a rational factual connection between the prohibition of fuel burning and the release of contaminants into the air. The objective of the Act was the control and suppression of air pollution. The prohibition of fuel burning unquestionably serves that end."

The air pollution evidence presented by the Western Oil and Gas Association in this Superior Court case showed its position there to be as lacking in merit as that before the Federal Power Commission.

POWER PLANT POLLUTION CONTROL IN LOS ANGELES COUNTY

Any discussion of control equipment per se to reduce air pollution from fossil fuel-fired boilers must necessarily be limited to power plant steam generators or other combustion equipment of comparable size. Attempts to reduce emissions from smaller units have mainly been concerned with the relatively heavy particulate concentrations emitted during soot blowing. Emissions are definitely influenced by burner and furnace design and configuration and some improvement can be achieved in this area, but the best approach to control of smaller units is to use cleaner fuels, such as natural gas.

The electric utility industry in Los Angeles County must be commended for its outstanding efforts to resolve its power plant pollution problem. The industry, in cooperation with the Air Pollution Control District, has made significant contributions in the development of means for reducing or controlling pollution from fuels combustion. Beginning in 1956 with the formation of the Joint Research Council on Power Plant Air Pollution Control, the combined talents of the electric utility industry in cooperation with the District were directed to the control of power plant pollution. Notable among the contributions of the industry to power plant pollution control has been the research to control sulfur oxides emissions, the development of two-stage combustion controls to reduce nitrogen oxides emissions, research on plume formation, experimental work on electrostatic precipitators and the bag filter house for particulate removal and, most recently, the vigorous efforts of the Southern California

Edison Company and the Department of Water and Power to obtain a year-round supply of natural gas for their steam generating stations.

Joint Research Council

The Joint Council was organized in March 1956 by the Southern California Edison Company, the Los Angeles Department of Water and Power, and the Los Angeles County Air Pollution Control District. The municipal electric utilities of Glendale, Burbank, and Pasadena joined the Council immediately upon its organization, and a short time later, the Air Pollution Control Districts of the adjacent Counties of Orange, San Bernardino, and Riverside became associate members of the Council. The Council's stated objective is "to arrive at a better understanding of the mutual problem and to develop a program to promote progress in the development of further corrective measures of control of air pollution from fuel burning power plants of electric utilities in the Los Angeles Basin, through cooperative efforts in the development and interpretation of data and free interchange of information related to air pollution; and to keep the membership advised of the activities and progress."

Control of Sulfur Oxides

Control of sulfur oxides has been given major attention by Council member agencies. Removal of the comparatively minute quantities of sulfur trioxide appears practical. Presently available commercial methods of removing sulfur dioxide have been investigated but none appears practical at this time for the low concentrations of this gas in the large volumes discharged from power plant stacks. Investigations of stack gas treatment for removal of sulfur dioxide and of possible methods of treatment of fuel to remove sulfur are being continued by Council members.

Visible Plume Control

Because of the State law on plume opacity, which is violated when fuel oil is burned by steam-electric generating plants in the Los Angeles Basin, a major part of the research efforts of the utility members has been directed toward determining the causes of plume opacity and means of reducing it. At present, some of the principle factors in plume opacity are known, but many others have not been determined as yet. Tests have been made to determine how plume opacity might be eliminated through variation of operating techniques, the use of chemical additives and mechanical and electrical devices. Although a complete solution to the plume opacity problem has not been found, the information which has been derived from these tests has brought the solution much closer. The Edison Company's adaptation of the electrostatic precipitator to fuel oil firing was a step forward in the control of particulate matter, but its effectiveness in controlling plume opacity was unsatisfactory.

Electrostatic Precipitator

The Edison Company initiated a precipitator test program for particulate removal and plume control early in 1955 in cooperation with the APCD. The first phase of this program was designed to investigate precipitator performance on a pilot plant basis. The electrostatic precipitation process was originally selected for pilot plant investigation on the basis of experience developed in coal fired power plants. Edison's pilot plant work demonstrated that major changes in precipitator design were necessary in order to obtain high collection efficiencies on the relatively low particulate load characteristics of oil fired boilers. As the result of nearly three years of intensive investigation, including the services of several consultants and an expenditure of over a half a million dollars, Edison ultimately obtained collection efficiencies of about 95-98 per cent on a pilot unit. Visual evidence also was obtained indicating excellent control of plume formation. Based on these results, Edison installed a full-scale prototype precipitator on its No. 2 unit at its El Segundo steam station in December 1958.

Edison's prototype plant, however, was a failure. Attempts to obtain the efficiency and practicability which had been indicated by the pilot plant investigations were unsuccessful. Although plume control was outstanding on the pilot unit, stack emissions from the full-scale unit did not comply with the District's opacity regulations. In addition, the equipment experienced numerous component failures and continued corrosion problems, which, in one instance, caused a complete boiler shutdown. Although installation and modification of the electrostatic precipitator by Edison has required over one million dollars in expenditures, it was Edison's final judgment that satisfactory performance and reliability could not be achieved with an electrostatic precipitator on oil-fired steam generators.

Two-Stage Combustion Controls

Experimental work by the Joint Council, and particularly by the Southern California Edison Company in cooperation with the Babcock and Wilcox Company over the past five years, has lead to the development of burner and equipment modifications on one type of power plant boiler design that reduces the average production of nitrogen oxides by about 40 per cent at full load operation. These modifications, which have been termed "two-stage combustion", are effective in reducing the formation of nitrogen oxides when either oil or natural gas is used as a fuel. In its present stage of technical development, two-stage combustion, as a control method, is applicable only to large front-fired power plant boilers. Theoretically, at least, two-stage combustion modifications are applicable to all power plant boilers; however, the adoption of this method would necessarily be preceded by a period of experimentation on each type of unit to be modified. In two-stage combustion, approximately 90 per cent of the air required for combustion is introduced at the burner tip. The remainder of combustion air is introduced through auxiliary airports installed above the burners. Major furnace modifications are required on existing boilers to permit the use of this type control. However, if incorporated in the original design, the modifications are comparatively minor.

Bag Filter House

Extensive research work and pilot plant studies by the Southern California Edison Company has led to the development of a full-scale prototype bag filter house as a means for controlling particulate emissions from fuel oil combustion. In the past, the bag filter house has been considered impractical for power plant application because of such inherent filter fabric limitations as temperature, pressure drop and fabric deterioration. Results of full-scale tests indicate that these limitations can be largely overcome by selection of suitable bag material and by the addition of alkaline additives to the gases entering the filter house. In operation, the bag filters are pre-coated with dolomite before startup. The additive is continually injected into the gas stream at two to three times the stoichiometric equivalent of the sulfur trioxide content of the flue gases. Sulfur trioxide reacts in the gas stream and on the surface of the bags to form calcium sulfate, a collectible solid. This control device removes only sulfur trioxide and particulates. It has no effect on sulfur dioxide or nitrogen oxides.

Edison's prototype bag filter house has been operated intermittently since February 15, 1965. Many equipment and operating difficulties have been encountered over the past year. Fabric deterioration and failure have required replacement of all 1200 filter bags at a cost in excess of $30,000. Other technical difficulties encountered with the baghouse have included:

1. Gas leakage into the bag compartments when baghouse is out of service resulting in condensation and corrosion problems.

2. Unequal distribution of stack gases in the baghouse.

3. Excessive pressure drop and accompanying high power requirements.

4. Fabric damage caused by filter bag clamps and mechanical problems with bag suspension systems.

5. Failure to obtain uniform distribution and deposition of powdered dolomite additive.

6. Caking of material on filter bags due to moisture.

7. Problems with reverse-flow bag cleaning operation.

8. Major difficulties with conveying and disposal of collected material.

Edison's expenditures for research, pilot plant studies and installation and testing of the full-scale prototype bag filter house have already exceeded $1,200,000. Experimentation and tests on the baghouse by Edison are expected to continue for at least another year. In view of Edison's experience with the electrostatic precipitator and the current status of their bag filter house, the APCD has concluded that there is presently no completely satisfactory method available for controlling contaminant emissions from fossil fuel burning power plants, other than to use natural gas.

Conclusions

Almost every projection of social and economic activity between 1960 and the year 2000 indicates that pollution from fossil fuels combustion will multiply many fold. 7/ 8/ A few key indicators are:

1. United States population will double.

2. Electric power production in the U.S. will increase from 850 billion kilowatt-hours per year to over 2800 billion killowatt-hours in 1980 and to about 3700 billion killowatt-hours in the year 2000.

3. In 1980, nearly two-thirds of the total electrical power requirements will be provided by fossil fuels and, in 2000, from 40 to 50 per cent will be provided by fossil fuels.

These estimates of national growth suggest that if we are concerned with the deterioration of our air environment now, we will have much more cause for anxiety in the next four decades. It is too often concluded that more effective technology must be developed or that more research must be done. Indeed, further research is needed, but there is a great deal which can be done right now. It is impossible to predict the point in time when critical concentration of pollutants in the atmosphere may be reached. Past experience has been that air pollution is virtually ignored until levels are reached where detrimental effects are observed. Control of pollution from fossil fuels combustion is one of the most compelling problems in air pollution today. Steps to reduce pollution from this source which are scientifically and technically possible must be taken now. To wait any longer is to wait too long.

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